Vitamin D fortification in the United States and Canada: current status and data needs[1–4]

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ABSTRACT

Most circulating 25-hydroxyvitamin D originates from exposure to sunlight; nevertheless, many factors can impair this process, necessitating periodic reliance on dietary sources to maintain adequate serum concentrations. The US and Canadian populations are largely dependent on fortified foods and dietary supplements to meet these needs, because foods naturally rich in vitamin D are limited. Fluid milk and breakfast cereals are the predominant vehicles for vitamin D in the United States, whereas Canada fortifies fluid milk and margarine. Reports of a high prevalence of hypovitaminosis D and its association with increased risks of chronic diseases have raised concerns regarding the adequacy of current intake levels and the safest and most effective way to increase vitamin D intake in the general population and in vulnerable groups. The usual daily intakes of vitamin D from food alone and from food and supplements combined, as estimated from the US third National Health and Nutrition Examination Survey, 1988-1994, show median values above the adequate intake of 5 μg/d for children 6-11 y of age; however, median intakes are generally below the adequate intake for female subjects > 12 y of age and men > 50 y. In Canada, there are no national survey data for estimation of intake. Cross-sectional studies suggest that current US/Canadian fortification practices are not effective in preventing hypovitaminosis D, particularly among vulnerable populations during the winter, whereas supplement use shows more promise. Recent prospective intervention studies with higher vitamin D concentrations provided evidence of safety and efficacy for fortification of specific foods and use of supplements. *Am J Clin Nutr* 2004;80(suppl):1710S–6S.

KEY WORDS Usual vitamin D intake, food fortification, dietary supplements, vitamin D insufficiency, dietary requirements, nutrition labeling

INTRODUCTION

Most circulating 25-hydroxyvitamin D originates from exposure to sunlight; however, seasonal changes, living at high latitudes, dark skin pigmentation, aging, and other factors can impair this process, necessitating periodic reliance on dietary sources to supply the needed precursor to 25-hydroxyvitamin D (1-4). Because so many environmental, cultural, and physiologic factors can impair sunlight-induced synthesis of vitamin D, most of us at some time in our lives are reliant on dietary sources to supply the essential precursor to 25-hydroxyvitamin D. The importance of dietary sources of vitamin D is reflected in the 1997 Dietary Guidelines for vitamin D intake established by the Institute of Medicine of the US National Academy of Science (5). This joint Canadian and American effort to establish guidelines for the adequate intake (AI) of vitamin D in the assumed absence of sunlight is discussed in depth elsewhere in these proceedings (6).

Circulating 25-hydroxyvitamin D concentrations are the best clinical indicators of overall vitamin D adequacy and represent the combined contributions of cutaneous synthesis and oral ingestion of dietary sources of vitamin D, including vitamin D_2 from plants and fungi and vitamin D_3 from animal sources, fortified foods, and supplements. In addition, the hepatic conversion of vitamin D_2 or vitamin D_3 to 25-hydroxyvitamin D is not under the tight hormonal regulation of parathyroid hormone, and circulating concentrations of 25-hydroxyvitamin D are not influenced by dietary calcium or phosphorus intake (6). Although the exact serum concentrations distinguishing vitamin D sufficiency from vitamin D insufficiency are controversial, it is clear that the prevalence of low circulating concentrations of 25-hydroxyvitamin D in the United States and Canada is increasing (7-15). Moreover, we are becoming increasingly aware of the link between these low concentrations of 25-hydroxyvitamin D and increased risks of chronic diseases, including diabetes mellitus, cancer, autoimmune disorders, and osteoporosis (1, 7, 16-26).

The US and Canadian populations are largely dependent on fortified foods and dietary supplements to meet their vitamin D needs during times of insufficient sunlight, because foods that are naturally rich in vitamin D are not frequently consumed. Natural concentrations of vitamin D in foods are variable. Fatty fish represents the richest natural source of vitamin D, with salmon being the type most commonly consumed in North America. Liver and other organ meats are also high in vitamin D but are not as popular as fish and are often avoided because of their high cholesterol content. Although mushrooms and egg yolks are listed as sources of vitamin D, the concentrations are often very low and variable, which results in poor documentation of the vitamin D content of these foods (27).

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LAWFUL ADDITION OF VITAMIN D TO FOODS IN CANADA AND THE UNITED STATES

Vitamin D is a fat-soluble vitamin with the potential for toxicity if it is chronically consumed at very high doses; therefore, in Canada and the United States, the addition of vitamin D to foods is very carefully regulated. In developing regulations concerning the lawful addition of vitamin D and calcium to foods, the 2 countries used the same dietary guidelines for AIs of vitamin D and calcium for all sex and age groups and the upper limits of safe intakes of vitamin D and calcium (5).

Canada currently has mandatory fortification of foods, through the Canadian Food and Drug Regulations (28). When a nutritional public health need is identified, the solution is to ensure that all people can benefit, and staple foods are fortified. In the case of vitamin D, the foods that require fortification with vitamin D are milk and margarine. In the case of milk, fluid milk "shall contain added vitamin D in such an amount that a reasonable daily intake of the milk contains not less than 300 IU and not more than 400 IU of vitamin D" (29). Fluid milk in Canada is labeled as providing 44% of the recommended daily intake (of 400 IU) per 250-mL serving. Other milk products that require vitamin D fortification are evaporated milk, powdered milk, and goat's milk. The proliferation of milks of plant origin (particularly soy) made it necessary to require calcium-fortified, plant-based milks to be fortified with vitamin D, as well as other nutrients (eg, vitamin B_{12}), to yield a nutrient profile similar to that of cow's milk (30). All margarines in Canada are fortified with vitamin D (530 IU/100 g) (31). Other foods for which vitamin D addition is permitted are meal replacements, nutritional supplements, and formulated liquid diets. The amounts of vitamin D added depend on the energy content and intended use of the product; for example, for formulated liquid diets, the amount may be no less than 100 IU and no more than 400 IU per 1000 kcal, as long as the intended total energy intake is $<$ 2500 kcal (32). Currently, with the exception of some egg products, no other fortification with vitamin D is permitted in food. Fortified milk may be used in food manufacturing (eg, yogurt) but, in general, industrial milk that is used for baking and for making milk products such as soft and hard cheeses does not need to be fortified (33).

In the past, there has been some confusion concerning the specific regulations that govern the addition of vitamin D to foods in the United States. These regulations have been confused with the fortification or nutritional quality guidelines for foods (34) and with current good manufacturing limitations associated with some direct food substances affirmed as generally recognized as safe (GRAS) (35). Vitamin D is an affirmed GRAS ingredient [21 Code of Federal Regulations (CFR) 184.1950]. Because its addition to foods as a nutrient supplement is in accordance with 21 CFR 184.1 (b) (2), its use has strict limitations with respect to the categories of foods, functional use, and level of use (36). In accordance with 21 CFR 184.1 (b) (2), any addition of vitamin D to foods not in compliance with each of these established limitations requires a food additive regulation. Such regulatory limitations provide a control mechanism that limits overfortification with vitamin D and thus eliminates some of the concerns regarding the increasing fortification of foods with calcium that is currently underway in the United States (37, 38).

Unlike Canada, where fortification with vitamin D is mandatory for designated foods, the addition of vitamin D to eligible foods in the United States is optional in most cases, with the exception of fortified milk. Fluid milk in the United States is not required to have vitamin D added unless the label declares that it is fortified. Vitamin D, which includes crystalline vitamin D_2 and D_3 and vitamin D_2 and D_3 resin formed from the irradiation of ergocalciferol and cholecalciferol, can be added as the sole source of added vitamin D in the food categories shown in **Table 1** and must not exceed the specified limitations (36). Vitamin D is also affirmed as GRAS for use in infant formula [21 CFR 184.1950 (c) (2)] and as an optional ingredient in margarine [21 CFR 184.1950 (c) (3)]. Vitamin D_3 is regulated as a direct food additive for use as a nutrient supplement in calcium-fortified fruit juices and fruit juice drinks (21 CFR 172.380). In addition, vitamin D may be added to olestra to compensate for any interference with absorption of fat-soluble vitamins, in accordance with 21 CFR 172.867 (14) (d).

In the United States, although many varieties of foods are eligible for controlled levels of vitamin D fortification, there is a large gap between the number of eligible foods and the number and variety of vitamin D-fortified foods observed in the US marketplace, as shown in Table 1. An unofficial limited survey of the local marketplace indicated that, for some of the food categories eligible for vitamin D fortification, few or no fortified products were found. Only 2 types of margarine, a few noodle and hot cereal products, and no macaroni, rice, or cornmeal products were fortified with vitamin D. Milk products such as yogurt, butter, ice cream, sour cream, cream, cottage cheese, and most varieties of hard and soft cheeses were not routinely fortified with vitamin D, which calls attention to a significant public misperception that all dairy products are rich sources of vitamin D (39). Actually, fluid milk is the only dairy food that is routinely fortified with vitamin D. In the United States, milk and ready-to-eat cereals are the predominant food sources of vitamin D (5, 7).

The amounts of vitamin D found in foods are indicated in the Nutrition Facts panel on the label. An example from a ready-to-eat breakfast cereal is shown in **Figure 1**. The vitamin D content is expressed not in micrograms or international units but as a percentage of a general dietary guideline that the Food and Drug Administration (FDA) uses for product labels. This guideline is the reference daily intake (RDI) or the more commonly used daily value (DV), which is 10 μg or 400 IU (40). The RDI/DV figures are not recommended intake levels, because of the impracticality of stating the age- and sex-specific intake guidelines on the small label; rather, they are reference values for nutrients developed by the US FDA to help consumers use the food label nutrition information (40). The DV is equivalent to the dietary reference intake (DRI) for men and women 51 to 70 y of age (AI: 400 IU or 10 μg) and is twice the DRI set for younger men and women (AI: 200 IU or 5 μg) (40). The vitamin D content shown on the label is expressed as a percentage of the DV and is usually derived from fortification or added vitamin D. As shown here, the usual fortification level for most ready-to-eat cereals is 10-35% DV or 40-140 IU. The intake level is higher if the product is consumed with milk, as indicated. In Canada, a similar labeling system was implemented in January 2003 (41). The vitamin D content should also be expressed only as a percentage of a DV; however, the DV for vitamin D in Canada is 5 μg (200 IU). Therefore, there is potential for confusion between the 2 countries, because the same amount of vitamin D in a food would result in different percentages of DV on the label.

TABLE 1
Lawful addition of vitamin D to foods in the United States

Category of food	21 CFR citation	Fortification status	Maximal level allowed[1]	Surveyed products fortified with vitamin D: Estimate of fortified products	Usual fortification level
Cereal flours and related products					
Enriched Farina	137.305	Optional	350 IU/100 g	Few	
Ready-to-eat breakfast cereals	137.305	Optional	350 IU/100 g	Most	40–140 IU (10–35% DV)
Enriched rice	137.350	Optional	90 IU/100 g	None	None
Enriched corn meal products	137.260	Optional	90 IU/100 g	None	None
Enriched noodle products	139.155	Optional	90 IU/100 g	None	None
Enriched macaroni products	139.115	Optional	90 IU/100 g	Very few	40 IU/252 g (10% DV)
Milk					
Fluid milk	131.110	Optional	42 IU/100 g	All	400 IU/quart or 946 mL
Acidified milk	131.111	Optional	42 IU/100 g	All	400 IU/quart or 946 mL
Cultured milk	131.112	Optional	42 IU/100 g	All	400 IU/quart or 946 mL
Concentrated milk	131.115	Optional	42 IU/100 g	All	400 IU/quart or 946 mL
Nonfat dry milk fortified with A and D	131.127	Required	42 IU/100 g	All	400 IU/quart or 946 mL
Evaporated milk, fortified	131.130	Required	42 IU/100 g	All	400 IU/quart or 946 mL
Dry whole milk	131.147	Optional	42 IU/100 g	All	400 IU/quart or 946 mL
Milk products					
Yogurt	131.200	Optional	89 IU/100 g	Few	40–80 IU/RACC[2]
Low fat yogurt	131.203	Optional	89 IU/100 g	Few	40–80 IU/RACC[2]
Nonfat yogurt	131.206	Optional	89 IU/100 g	Few	40–80 IU/RACC[2]
Margarine	166.110	Optional	331 IU/100 g	Few	40–140 IU/RACC
Calcium-fortified fruit juices and drinks[3]	172.380	Optional	100 IU/RACC	NA[4]	100 IU/RACC

[1] Maximal level of vitamin D that can be added in accordance with 21 CFR 184.1 (b) (2) for the category of food.
[2] RACC, reference amount customarily consumed or the US FDA regulatory serving size.
[3] Vitamin D_3 may be added, at levels not to exceed 100 IU per serving, to 100% fruit juices, excluding fruit juices that are specially formulated or processed for infants, which are fortified with > 33% of the RDI of calcium per serving.
[4] NA, not appropriate; it is premature to evaluate the number of products in the market place given that the regulation was approved in April 2003.

ESTIMATES OF VITAMIN D INTAKE

In the absence of nationally representative survey data for Canada, vitamin D intakes cannot be accurately estimated; however, values can be determined for the US population with data from the third National Health and Nutrition Examination Survey (NHANES III), which was conducted in 1988–1994. NHANES III is a national probability survey designed to yield nationally representative estimates of the health and nutritional status of the US population, with data collected from all latitudes in the contiguous United States (25–45° N) (42). We used the survey data to estimate vitamin D intakes for 8 specific age and sex groups in the US population. Our study cohort consisted of female and male subjects 6–11 y of age (female: $n = 1553$; male: $n = 1581$), 12–19 y (female: $n = 1599$; male: $n = 1462$), 20–49 y (female: $n = 4546$; male: $n = 4199$), and ≥ 50 y (female: $n = 3554$; male: $n = 3271$). The NHANES III database contains estimates of nutrient intakes derived from a 24-h dietary recall conducted during an extensive interview with each participant. For selected individuals, a second 24-h recall was conducted for estimation of the day-to-day variations in nutrient intake, which would allow calculation of the usual dietary intake. The database also contains information on the frequency of use, number of units consumed per time, and nutrient contents per unit for each dietary supplement product the participants used during a 1-mo period. To estimate the usual dietary intake from the 24-h intake, we used the approach of the National Academy of Sciences (43). Vitamin D intake from dietary supplements was calculated through multiplication of the frequency of use of vitamin D-containing supplements during the 1-mo period by the number of units (eg, tablet, pill, or capsule) consumed each time and by the vitamin D potency per unit. We used a conversion factor of 30.4 to estimate the average daily vitamin D intake from supplements from the data on vitamin D intake per month. The usual intake of vitamin D from food plus supplements was calculated through addition of estimates of an individual's average daily vitamin D intake from supplements and the usual vitamin D intake from food. We used SUDAAN procedures (software version 7.5.6) (44) to estimate group means and SEM values. These procedures account for the complex sample design used in NHANES III. For data describing racial and ethnic differences in vitamin D intake, we used simple t tests to compare group mean nutrient intakes according to self-identified race/ethnicity. Complex survey sample weights were used in all statistical analyses, to produce nationally representative estimates.

Nationally representative mean ± SEM and 50th percentile usual intakes for vitamin D for 8 age/sex groups are presented in **Table 2** for white, African American, and Mexican American subjects. The estimated intake of vitamin D from food alone is shown in the upper part of Table 2, and the intake from both food and supplements is shown in the lower part. Both the mean and median intakes from all sources meet the AI for children 6–11 y of age but not for most adult men and women ≥ 50 y. Among children 6–11 y of age, Mexican Americans have significantly higher intakes than do African Americans and whites. In general, vitamin D intakes from all sources are higher for men than for women. Among subjects 12–19 y and ≥ 20 y of age, whites

Nutrition Facts

Serving Size ¾ cup (30g)
Servings Per Container About 17

Amount Per Serving	Whole Grain Total	with 1/2 cup skim milk
Calories	110	150
Calories from Fat	10	10
	% Daily Value**	
Total Fat 1g*	1%	1%
Saturated Fat 0g	0%	0%
Polyunsaturated Fat 0g		
Monounsaturated Fat 0g		
Cholesterol 0mg	0%	1%
Sodium 190mg	8%	11%
Potassium 90mg	3%	8%
Total Carbohydrate 23g	8%	10%
Dietary Fiber 3g	10%	10%
Sugars 5g		
Other Carbohydrate 15g		
Protein 2g		
Vitamin A	10%	15%
Vitamin C	100%	100%
Calcium	100%	110%
Iron	100%	100%
Vitamin D	10%	25%
Vitamin E	100%	100%
Thiamin	100%	100%
Riboflavin	100%	110%
Niacin	100%	100%
Vitamin B_6	100%	100%
Folic Acid	100%	100%
Vitamin B_{12}	100%	110%
Pantothenic Acid	100%	100%
Phosphorus	8%	20%
Magnesium	6%	10%
Zinc	100%	100%
Copper	4%	4%

* Amount in Cereal. A serving of cereal plus skim milk provides 1g total fat, less than 5mg cholesterol, 260mg sodium, 290mg potassium, 29g total carbohydrate (11g sugars) and 7g protein.
** Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

FIGURE 1. Nutrition Facts panel from a US ready-to-eat cereal product. The vitamin D content of a serving of ready-to-eat cereal is shown with milk (25%, 100 IU) and without milk (10%, 40 IU). In the United States, milk and ready-to-eat cereals serve as the predominant food sources of vitamin D.

consume significantly more vitamin D than do African Americans and Mexican Americans. African Americans, with the greatest physiologic need for dietary sources of vitamin D, have the lowest intake from food alone and food plus supplements.

From the NHANES III data, it is evident that the use of dietary supplements is associated with increases in daily vitamin D intakes of ∼2–3 μg. North Americans probably have the highest vitamin D intakes, from both food and supplements, in the world. Nowson and Margerison (45) provided evidence in support of this statement. They grouped estimates of dietary vitamin D intakes for different countries according to the level of food fortification practiced. Countries in which milk, margarine, and other foods are fortified with vitamin D showed 2–3 μg higher intakes than did those in which only margarine or milk and margarine are fortified.

Traditionally, estimates of the usual vitamin D intake from the NHANES III data could be used to assess the adequacy of vitamin D intake in the healthy US population. However, this approach to nutrient intake assessment is valid only when there is an established estimated average requirement (EAR) (46). There is no established EAR for vitamin D, and the AI has inherent limitations for assessment of vitamin D intake adequacy among groups (46). According to the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes (46), the AI is expected to meet or exceed the amount needed to maintain a defined nutritional state or criterion of adequacy for essentially all members of the apparently healthy population. With respect to vitamin D, a defined nutritional state refers specifically to maintenance of serum 25-hydroxyvitamin D concentrations above the concentration below which vitamin D deficiency rickets or osteomalacia occurs regardless of sun exposure (46). The AI for vitamin D was not based on observed mean intakes of population groups, and the Institute of Medicine (46) determined that the AI cannot be used to calculate the prevalence of inadequate nutrient intakes for groups; furthermore, when mean group intakes are below the AI, assumptions cannot be made regarding inadequacies of intakes. For this reason, we refrain from estimating the prevalence of dietary vitamin D inadequacy on the basis of the NHANES III intake data and simply point out that, for most older adults in the United States, mean intakes of vitamin D are well below the AI. These findings support the need for reevaluation of the DRI for vitamin D and underscore the critical need to establish an EAR for vitamin D.

EFFICACY OF CURRENT FORTIFICATION STRATEGIES IN PREVENTING VITAMIN D INSUFFICIENCY

Cross-sectional studies suggested that current US/Canadian fortification practices are not effective in preventing hypovitaminosis D, particularly among vulnerable populations during winter (8–13, 47). Cross-sectional studies in the United States and Canada also revealed that meeting the DRI for vitamin D intake is not sufficient to prevent vitamin D insufficiency in the winter in Canada (8) and throughout the year among younger and older African American women in the United States (13, 47). The strong association between vitamin D insufficiency and risks of chronic diseases has raised concerns regarding the efficacy of current fortification mechanisms, such as milk fortification, in the United States and Canada to prevent low circulating concentrations of vitamin D (7). Chronic disease risks were linked directly to low vitamin D intake, with significantly greater risks of type 1 diabetes mellitus (18), rheumatoid arthritis (48), multiple sclerosis (49), and hip fractures (50). Many randomized, placebo-controlled studies have demonstrated that higher concentrations of vitamin D administered as dietary supplements (∼800–1200 IU/d or 20–30 μg/d) are effective in reducing fracture rates among elderly subjects (51–53). We know much less about the efficacy of vitamin D fortification of foods in reducing the risks of osteoporosis and other chronic diseases.

Most studies that explored the safety and efficacy of fortifying milk with vitamin D either were limited to measurements of changes in circulating concentrations of 25-hydroxyvitamin D or were conducted for too short a time for accurate detection of changes in bone mineral density or other endpoints (54, 55). Only recently did intervention studies successfully demonstrate the safety and efficacy of milk as a fortification vehicle for vitamin D among Chinese women living in Malaysia (56, 57). In the most recent study, the powdered milk product was fortified to a higher vitamin D level than used in the United States or Canada (ie, 10 μg/d vitamin D and 1200 mg/d calcium) (57). Consumption of

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TABLE 2
Vitamin D intake estimates from food alone and from food and supplements among white, African American, and Mexican American men and women

	Vitamin D intake[1]							
	Women				Men			
	6–11 y	12–19 y	20–49 y	≥50 y	6–11 y	12–19 y	20–49 y	≥50 y
	μg/d							
AI	5	5	5	10–15	5	5	5	10–15
Usual vitamin D intake from food only								
White								
Mean ± SEM	5.54 ± 0.179	5.18 ± 0.215	4.35 ± 0.097	4.68 ± 0.075	6.66 ± 0.226	6.95 ± 0.300	5.70 ± 0.157	5.72 ± 0.121
Median	5.1	4.3	3.7	4.0	6.2	5.9	4.6	4.9
No.	413	439	1442	1974	419	353	1238	1802
African American								
Mean ± SEM	5.34 ± 0.111	4.21 ± 0.155	3.68 ± 0.075	3.84 ± 0.111	5.76 ± 0.128	5.84 ± 0.249	4.91 ± 0.143	4.55 ± 0.247
Median	4.8	3.5	2.8	3.3	5.5	4.7	3.7	3.4
No.	512	567	1557	777	540	521	1298	688
Mexican American								
Mean ± SEM	6.29 ± 0.163	4.80 ± 0.140	3.97 ± 0.093	3.91 ± 0.205	6.84 ± 0.196	6.14 ± 0.222	4.84 ± 0.123	4.28 ± 0.125
Median	5.9	4.1	3.3	3.3	6.4	5.1	3.8	3.4
No.	567	498	1330	657	539	511	1475	667
Usual vitamin D intake from food and supplements								
White								
Mean ± SEM	8.09 ± 0.283	6.47 ± 0.283	7.33 ± 0.262	8.37 ± 0.319	9.58 ± 0.336	8.43 ± 0.429	8.12 ± 0.335	8.11 ± 0.212
Median	6.4	5.1	4.9	5.4	8.1	6.7	5.8	6.10
No.	413	439	1442	1974	419	353	1238	1802
African American								
Mean ± SEM	8.27 ± 0.296	5.24 ± 0.219	5.73 ± 0.196	5.94 ± 0.286	7.45 ± 0.174	6.74 ± 0.412	6.9 ± 0.236	5.96 ± 0.279
Median	5.6	3.8	3.5	4.0	6.1	4.9	4.2	3.8
No.	512	567	1557	777	540	521	1298	688
Mexican American								
Mean ± SEM	8.01 ± 0.256	5.94 ± 0.257	5.69 ± 0.264	5.95 ± 0.291	8.54 ± 0.486	7.36 ± 0.420	6.16 ± 0.209	6.13 ± 0.244
Median	6.7	4.5	3.9	3.8	7.1	5.4	4.3	4.2
No.	567	498	1330	657	539	511	1475	667

[1] Weighted mean ± SEM values and 50th percentile (median) intakes.

the fortified milk for 24 mo significantly increased serum 25-hydroxyvitamin D concentrations and effectively reduced bone loss at the lumbar spine and hip, compared with the control group (57). That study presented compelling evidence that milk can be an effective vehicle for vitamin D fortification; however, we cannot ignore the current barriers to the use of milk as a food vehicle for vitamin D in North America.

CURRENT BARRIERS TO ADEQUATE VITAMIN D INTAKE

Many of the barriers that keep the current vitamin D fortification practices from preventing hypovitaminosis D are attributable to problems with the consumption of fluid milk. First, the amount of vitamin D added to milk may not be adequate to produce the desired health changes or even to increase circulating 25-hydroxyvitamin D concentrations. Second, milk is not uniformly consumed in the United States and Canada, and both countries have experienced pronounced declines in the overall consumption of milk in the past decade (39). In addition, only a few eligible milk products are fortified with vitamin D, such as a few brands of yogurt, and the concentrations in those products are variable. Furthermore, the racial/ethnicity groups at greatest risk of vitamin D insufficiency consume less milk and ready-to-eat cereal than do their white counterparts (7). Finally, the vitamin D contents of food are variable, which can confound analyses because of inaccurate nutrient content information.

Focusing on improving our nutrient database of the vitamin D contents of foods may be an exercise in futility, because the vitamin D contents of foods that are naturally rich in vitamin D can vary according to the season and climatic conditions, the fortification of foods in the marketplace is in constant flux, and the added vitamin D content of fluid milk varies significantly with the procedures used to fortify the milk. These procedures include general storage conditions for the vitamin preparation, the method used to add vitamin D to the milk, and the point during processing at which the vitamin D preparation is added to the milk (58–62). Standardization of such processes among dairies from state to state and from province to province might significantly improve the quality control of vitamin D fortification of milk. Surveys examining the compliance of dairies with vitamin D fortification regulations in the United States (58–60, 62) and Canada (59, 61) indicated that a large proportion of the samples were not in compliance, with most of those samples being underfortified with vitamin D.

Strategies to improve food fortification may help the general population achieve adequate vitamin D status during the winter, and new products such as calcium- and vitamin D-fortified orange juice (63) may help many people overcome the barriers involving milk consumption. We also need to better understand

how certain vitamin D fortification-eligible staple foods, such as cheese and bread, could be used to improve the vitamin D status of the general population, because it is lawful in the United States to fortify both of these food staples with vitamin D, provided the amount of vitamin D added does not exceed the limitations listed for dairy and grain products, respectively, in 21 CFR 184.1950. Others provided evidence that vitamin D is stable and bioavailable from these foods (64, 65). Food fortification strategies, however, may not be effective during the winter for groups at greatest risk, ie, dark-skinned and elderly subjects, for whom higher doses administered as dietary supplements might be the only way to effectively increase serum 25-hydroxyvitamin D concentrations (47). We clearly need more information from prospective intervention studies to determine the best approach to preventing hypovitaminosis D among vulnerable subpopulations.

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REFERENCES

1. Holick MF. Vitamin D: the underappreciated D-lightful hormone that is important for skeletal and cellular health. Curr Opin Endocrinol Diabetes 2002;9:87–98.
2. Norman A. Sunlight, season, skin pigmentation, vitamin D, and 25-hydroxyvitamin D: integral components of the vitamin D endocrine system. Am J Clin Nutr 1998;67:1108–10.
3. Webb AR, Kline L, Holick MF. Influence of season and latitude on the cutaneous synthesis of vitamin D_3: exposure to winter sunlight in Boston and Edmonton will not promote vitamin D_3 synthesis in human skin. J Clin Endocrinol Metab 1988;67:373–8.
4. Clemens TL, Adams JS, Henderson SL, Holick MF. Increased skin pigmentation reduces the capacity of skin to synthesize vitamin D_3. Lancet 1982;1:74–6.
5. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, Institute of Medicine. Vitamin D. In: Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. Washington, DC: National Academy Press, 1997:250–87.
6. Weaver CM, Fleet JC. Vitamin D requirements: current and future. Am J Clin Nutr 2004;80(suppl):1735S–9S.
7. Calvo MS, Whiting SJ. Prevalence of vitamin D insufficiency in Canada and the United States: importance to health status and efficacy of current food fortification and dietary supplement use. Nutr Rev 2003;61:107–13.
8. Veith R, Cole DE, Hawker GA, Trang HM, Rubin LA. Wintertime vitamin D insufficiency is common in young Canadian women and their vitamin D intake does not prevent it. Eur J Clin Nutr 2002;55:1091–7.
9. Rucker D, Allan JA, Fick GH, Hanely DA. Vitamin D insufficiency in a population of healthy western Canadians. Can Med Assoc J 2002;166: 1517–24.
10. Looker AC, Dawson-Hughes B, Calvo MS, Gunter EW, Sahyoun NR. Serum 25-hydroxyvitamin D status of adolescents and adults in two seasonal subpopulations from NHANES III. Bone 2002;30:771–7.
11. Tangpricha V, Pearce EN, Chen TC, Holick MF. Vitamin D insufficiency among free-living healthy young adults. Am J Med 2002;112: 659–62.
12. Thomas MK, Lloyd-Jones DM, Thadhani RI, et al. Hypovitaminosis D in medical inpatients. N Engl J Med 1998;338:777–83.
13. Nesby-O'Dell S, Scanlon KS, Cogswell ME, et al. Hypovitaminosis D prevalence and determinants among African American and white women of reproductive age: third National Health and Nutrition Examination Survey, 1988–1994. Am J Clin Nutr 2002;76:187–92.
14. Welch TR, Bergstrom WH, Tsang RC. Vitamin D-deficient rickets: the reemergence of a once-conquered disease. J Pediatr 2000;137:143–5.
15. Carvalho NF, Kenney RD, Carrington PH, Hall DE. Severe nutritional deficiencies in toddlers resulting from health food milk alternatives. Pediatrics 2001;107:1–7.
16. John EM, Schwartz GG, Dreon DM, Koo J. Vitamin D and breast cancer risk: the NHANES I Epidemiologic Follow-up Study, 1971–1975 to 1992. Cancer Epidemiol Biomarker Prev 1999;8:399–406.
17. Cantorna MT. Vitamin D and autoimmunity: is vitamin D status an environmental factor affecting autoimmune disease prevalence? Proc Soc Exp Biol Med 2000;223:230–3.
18. Hypponen E, Laara E, Reunanen A, Jarvelin M-R, Virtanen SM. Intake of vitamin D and risk of type 1 diabetes: a birth-cohort study. Lancet 2001;358:1500–3.
19. Grant WB. An estimate of premature cancer mortality in the US due to inadequate doses of solar ultraviolet-B radiation. Cancer 2002;94:1867–75.
20. Freedman DM, Doesemeci M, McGlynn K. Sunlight and mortality from breast, ovarian, colon, prostate, and non-melanoma skin cancer: composite death certificate based case-control study. Occup Environ Med 2002;59:257–62.
21. Feldman D, Zhao X-Y, Krishnan AV. Vitamin D and prostate cancer. Endocrinology 2000;141:5–9.
22. Levine AJ, Harper JM, Ervin CM. Serum 25-hydroxyvitamin D, dietary calcium intake, and distal colorectal adenoma risk. Nutr Cancer 2001; 39:35–41.
23. Shin M-H, Holmes MD, Hankinson SE, Wu K, Colditz GA, Willet W. Intake of dairy products, calcium and vitamin D and risk of breast cancer. J Natl Cancer Inst 2002;94:1301–11.
24. Zehnder D, Bland R, Chana RS, et al. Synthesis of 1,25-dihydroxyvitamin D_3 by human endothelial cells is regulated by inflammatory cytokines: a novel autocrine determinant of vascular adhesion. J Am Soc Nephrol 2002;13:621–9.
25. Colston KW, Hansen CM. Mechanisms implicated in the growth regulatory effects of vitamin D in breast cancer. Endocr Relat Cancer 2002; 9:45–59.
26. Stene L, Joner G, Norwegian Childhood Diabetes Study Group. Use of cod liver oil during the first year of life is associated with lower risk of childhood-onset type 1 diabetes: a large, population-based case-control study. Am J Clin Nutr 2003;78:1128–34.
27. Nakamura K, Nashimoto M, Okuda Y, Ota T, Yamamoto M. Fish as a major source of vitamin D in the Japanese diet. Nutrition 2002;18: 415–6.
28. Health Canada. Consolidation of the Food and Drugs Act and the Food and Drug Regulations. Internet: http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/act-loi/e_index.html (accessed 16 December 2003).
29. Health Canada. Food & Drug Act B.08.003. Internet: http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/act-loi/pdf/e_b-text-1.pdf (accessed 16 December 2003).
30. Health Canada. Interim marketing authorization. Internet: http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/ima--amp/e_plant_based_beverages.html (accessed 16 December 2003).
31. Health Canada. Food & Drug Act B.09.016. Internet: http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/act-loi/pdf/e_b-text-1.pdf (accessed 16 December 2003).
32. Health Canada. Food & Drug Act B.24.102. Internet: http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/act-loi/pdf/e_d-text-2.pdf (accessed 16 December 2003).
33. Health Canada. Food & Drug Act B.01.404. Internet: http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/act-loi/pdf/e_b-text-1.pdf (accessed 16 December 2003).
34. US Food and Drug Administration. Nutritional quality guidelines for foods. Internet: http://www.accessdata.fda/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=104.20 (accessed 22 August 2003).
35. US Food and Drug Administration. Direct food substances affirmed as generally recognized as safe. Internet: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=184& (accessed 16 December 2003).
36. US Food and Drug Administration. Direct food substances affirmed as generally recognized as safe. Subpart B. Listing of specific substances affirmed as GRAS. Sec 184.1950 vitamin D. Internet: http://www.accessdata.fda.gov/scripts/cdrh/cfcfr/CFRSearch.cfm?fr=184.1950 (accessed 22 August 2003).
37. Johnson-Down L, L'Abbe MR, Lee NS, Gray-Donald K. Appropriate calcium fortification of the food supply presents a challenge. J Nutr 2003;133:2232–38.
38. Sutton NA. The safety of calcium fortification. Med Health RI 2000;83: 364–6.

39. Calvo MS. Dietary considerations to prevent loss of bone and renal function. Nutrition 2000;16:564–6.
40. US Food and Drug Administration. Reference daily intakes. Internet: http://www.fda.gov/fdac/special/foodlabel/rditabl.html (accessed 5 September 2003).
41. Health Canada. Nutrition labelling. Internet: http://www.hc-sc.gc.ca/hpfb-dgpsa/onpp-bppn/labelling-etiquetage/index_e.html (accessed 2 January 2004).
42. National Center for Health Statistics. Third National Health and Nutrition Examination Survey 1988–1994, NHANES III laboratory data file (CD-ROM). Hyattsville, MD: Centers for Disease Control and Prevention, 1996 (CD-ROM series 11, no. 1, revised October 1997; public use data file documentation no. 76200).
43. Looker AC, Sempos CT, Liu KA, Johnson CL, Gunter EW. Within-person variance in biochemical indicators of iron status: effects on prevalence status estimates. Am J Clin Nutr 1990;52:541–71.
44. Shah BV, Barnwell BG, Bieler GS. SUDAAN user's manual, release 7.56. Research Triangle Park, NC: Research Triangle Institute, 1995.
45. Nowson CA, Margerison C. Vitamin D intake and vitamin D status of Australians. Med J Aust 2002;177:149–52.
46. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, Institute of Medicine. Vitamin D. In: Dietary reference intakes: applications in dietary assessment: a report of the Subcommittees on Interpretation and Uses of Dietary Reference Intakes and Upper Reference Levels of Nutrients. Washington, DC: National Academy Press, 2000:106–12.
47. Harris SS, Soteriades E, Dawson-Hughes B. Secondary hyperparathyroidism and bone turnover in elderly blacks and whites. J Clin Endocrinol Metab 2001;86:3801–4.
48. Merlino LA, Curtis J, Mikuls TR, Cerhan JR, Criswell LA, Saag KG. Vitamin D intake is inversely associated with rheumatoid arthritis: results from the Iowa Women's Health Study. Arthritis Rheum 2004;50:72–7.
49. Munger KL, Zhang SM, O'Reilly E, et al. Vitamin D intake and incidence of multiple sclerosis. Neurology 2004;62:60–5.
50. Feskanich D, Willet WC, Colditz GA. Calcium, vitamin D, milk consumption, and hip fractures: a prospective study among postmenopausal women. Am J Clin Nutr 2003;77:504–11.
51. Chapuy MC, Arlot ME, Delmas PD, Meunier PJ. Effect of cholecalciferol treatment for three years on hip fractures in elderly women. BMJ 1994;308:1081–2.
52. Dawson-Hughes B, Harris SS, Krall EA, Dallal GE. Effect of calcium and vitamin D supplementation on bone density in men and women 65 years of age or older. N Engl J Med 1997;337:670–6.
53. Lips P, Graafmans WC, Ooms ME, Bezemer PD, Bouter LM. Vitamin D supplementation and fracture incidence in elderly persons: a randomized, placebo-controlled clinical trial. Ann Intern Med 1996;124:400–6.
54. McKenna MJ, Freaney R, Byrne P, et al. Safety and efficacy of increasing wintertime vitamin D and calcium intake by milk fortification. Q J Med 1995;88:895–8.
55. Keane EM, Healy M, O'Moore R, Coakley D, Walsh JB. Vitamin D-fortified liquid milk: benefits for the elderly community-based population. Calcif Tiss Int 1998;62:300–2.
56. Lau EMC, Lynn H, Chan YH, Woo J. Milk supplementation prevents loss in postmenopausal Chinese women over 3 years. Bone 2002;32:536–40.
57. Chee WSS, Suriah AR, Chan SP, Zaitun Y, Chan YM. The effect of milk supplementation on bone mineral density in postmenopausal Chinese women in Malasia. Osteoporos Int 2003;14:828–34.
58. Tanner JT, Smith J, Defibaugh P, et al. Survey of vitamin content of fortified milk. J Assoc Off Anal Chem 1988;71:607–10.
59. Chen TC, Shao A, Heath H III, Holick MF. An update on the vitamin D content of fortified milk from the United States and Canada. N Engl J Med 1993;329:1507.
60. Hicks T, Hansen AP, Rushing JE. Procedures by North Carolina dairies for vitamins A and D fortification of milk. J Dairy Sci 1996;79:329–33.
61. Faulkner H, Hussein A, Foran M, Szijarto L. A survey of vitamin A and D contents of fortified fluid milk in Ontario. J Dairy Sci 2000;83:1210–16.
62. Murphy SC, Whited LJ, Rosenberry LC, Hammond BH, Bandler DK, Boor KJ. Fluid milk vitamin fortification compliance in New York State. J Dairy Sci 2001;84:2813–20.
63. Tangpricha V, Koutkia P, Rieke SM, Chen TC, Perez AA, Holick MF. Fortification of orange juice with vitamin D: a novel approach for enhancing vitamin D nutritional health. Am J Clin Nutr 2003;77:1478–83.
64. Upreti P, Mistry VV, Warthesen JJ. Estimation and fortification of vitamin D_3 in pasteurized process cheese. J Dairy Sci 2002;85:3173–81.
65. Pietrek J, Preece MA, Windo J, et al. Prevention of vitamin D-deficiency in Asians. Lancet 1976;7970:1145–8.